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CONTRIBUTIONS FROM THE JEFFERSON PHYSICAL LABORATORY, HARVARD UNIVERSITY.

ELECTRIC DISCHARGES.

I. *SLOW MOVING ELECTRICAL LUMINOUS EFFECTS.*
II. *MAGNETIC FIELD AND ELECTRIC DISCHARGES.*

BY JOHN TROWBRIDGE.

WITH FOUR PLATES.

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ELECTRIC DISCHARGES.

By John Trowbridge.

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I. Slow Moving Electrical Luminous Effects.

Our knowledge of electrical manifestations is based upon the comparatively feeble effects which we can produce in laboratories; and even with the best appliances which modern applications of electricity afford we are far within the limit of lightning discharges.

It is unsafe, therefore, to assume that the testimony of many observers in regard to ball lightning and slow moving discharges, observed by them in electric storms, has its origin in disordered nerves. The following experiments lead me to believe that a slow ionization of rarefied air might be caused by currents of electricity of great strength following lanes of such rarefied air in thunder-storms.

The most notable experiments upon slow moving electrical luminous effects are those of Rhigi.[1] He charged condensers of large capacity by means of an electrical machine; discharged them through a large liquid resistance, and observed globular or elongated spindle-shaped discharges which moved slowly along the tubes of rarefied gases. He gives reasons for believing that such discharges are not striae, but that they belong to a particular kind of discharge.

It is to be noted that he interposed a spark gap in the discharge circuit.

I have repeated Rhigi's results, using instead of discharges from large condensers the current from a storage battery of 10,000 cells without the interposition of a spark gap, and I obtain slow moving luminous effects such as are represented in the illustrations of his memoir. These

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[1] Nuove Esperienze sulle Scintille Electriche, Constituite Da Masse Luminose che si Muovono Lentamente. R. Accademia, delle Scienze dell Instituo di Bologna, 19 Maggio, 1895.

luminous masses are shot out from the anode and move toward the cathode with increasing strength of current, and retreat to the anode with decreasing strength of current. A striking fact, however, is this: The movement of the luminous masses is toward the negative pole when the pressure in the tube is suddenly increased by a small amount. This movement, however, is dependent upon the strength of the current flowing through the tube, and cannot be perceived with feeble currents. I have employed currents from 10 milliamperes to 40 milliamperes. The number of luminous masses increases with the strength of current. The method of experimenting was as follows.

The current was led to a reservoir of water. At the base of the reservoir the water flowed out through a long glass tube of 1 cm. internal diameter. A wire introduced in this tube could be pushed in or out, thus modifying the resistance of the circuit. This high resistance was found sufficiently exact for the character of the experimentation. A milliamperemeter (Siemens and Halske) was introduced in the circuit of this water resistance and the exhausted tube while the water was kept running. The indications of the milliamperemeter were perfectly steady. Other forms of high resistance which I have tried heat under the powerful currents necessary for the production of the movements of the luminous masses. Running water gave, as far as the indications of the milliamperemeter was concerned, a perfectly steady resistance; when a telephone, however, was introduced in the circuit, rumbling crepitations were heard, due probably to electrolysis in the liquid. The exhausted tube also produces a note which is superposed on the rumbling of the liquid resistance. This latter note is especially noticeable in comparatively large tubes. I experimented first with a tube 60 cm. long, 8 cm. wide, provided with circular flat electrodes 3 cm. in diameter. The striae were in constant movement, producing a loud hum in the telephone introduced in the circuit. It was noticeable that the striae were straight; not curved toward the positive electrode, except near the sides of the tube, where a curvature like that of a liquid meniscus was formed.

The tubes were maintained in connection with a mercury pump, by means of which the pressure in the tubes could be changed to any desirable extent.

The slow movement of the luminous masses was best shown in tubes of 4 cm. internal diameter. Figure 1 is a photograph of a typical form of such slow moving luminous effects. It will be noticed that the ends of the mass are curved as if the centre of the mass constituted a positive

pole; the intervals between the masses acting like cathode spaces, the number of luminous masses increases with the strength of the current passing through the tube. They seem to be shot slowly out of the positive pole, and in their movement constitute a very beautiful experiment. The accompanying table represents this increase of the masses with increase of current.

Current in Milliamperes.	No. of Masses.
5	1
9	2
11	3
12	4
15	5
20	Continuous discharge from one terminal to the other.
40	

It would seem that the chain of positive and negative intervals with very powerful currents becomes a chain with infinitely small intervals between the positive and negative masses. Perhaps this is also the mechanism of the electric discharge through solid conductors. The pressure in the tube varied from four centimeters to half a centimeter. With lower pressures the ordinary form of striae was obtained. With narrow tubes the curvature of the striae increased, and the striae were apparently firmly held by the walls of the tube, recalling the phenomenon of the liquid meniscus. If we suppose, according to Townshend's hypothesis, that the striae indicate the collision of positive and negative ions, this collision would probably be modified by changes of velocity of collision near the walls of the tube in much the same way that the molecular actions at the surface of a fluid are modified by the attracting forces of the containing tube.

I believe that the slow movement observed by Rhigi is an ionization change produced by a change of pressure resulting from the heat of discharge of a condenser, combined with a change in electric potential. It has nothing to do with the velocity of the electric impulses, and cannot be called a slow movement of electricity. It seems probable that globe or ball lightning, and other apparently slow movements of luminous effects observed in thunder-storms, are of the nature of the ionization effects described in this paper.

The ionization theory of Townshend to my mind is the best explanation of these slow moving luminous effects. One can conceive of a non-

luminous condition of ionization pervading the space between the poles of a battery in a wide tube at a comparatively high pressure of the containing gas, perhaps 3 centimeters. The positive carriers are not restrained or held back by the swifter moving negative carriers, which cannot manifest their energy in a limited free path. On a sudden increase of pressure luminous clouds emerge from the anode. This phenomenon seems to indicate a greater proportional falling off in the energy of the negative carriers and a manifestation of superior energy of the positive carriers. The cloud of collision between the two moves slowly to the negative pole, the conductivity of the gas changing under the difference of potential to which the tube is subjected. Two luminous clouds can be formed by a suitable change of pressure in the tube; a change of pressure easily produced by condenser discharges in a side tube. These clouds, after the cessation of the condenser discharges, travel slowly to the negative pole in the tube, and coalesce before they disappear in this pole. We seem to have here a picture of the relative energy of the positive and negative carriers with the war of collision between them evidenced by the slow moving luminous clouds. The forms of these slow moving luminous effects are perfectly represented by the illustrations in Professor Rhigi's memoir. It is noteworthy that such slow moving electrical clouds can be produced by a steady discharge from a storage battery of ten thousand cells as well as with a powerful discharge from a large condenser through a water resistance, as in the case of Rhigi's experiments.

The form of the electrodes is of considerable importance. If the positive terminal is an aluminum plate of comparatively large diameter, four centimeters, and the negative terminal a point, the luminous masses retreat to the positive pole instead of moving to the negative pole on an increase of pressure. The surface density on the positive plate does not seem sufficient to force a volume ionization through the increase in the volume of the gas.

On the contrary, when the positive terminal is a point and the negative terminal the plane, an increase of pressure, with strong currents, causes a slow movement of the luminous masses to the negative pole.

A constriction in the glass tube results, in the formation in the constriction, of a fixed luminous mass which acts as a cathode. The position of a side entrance to the tube leading to the pump does not seem to have any influence on the position of the luminous masses. Perhaps the most interesting case of slowly moving electric luminous discharges is that of the very slow retreat of the positive column when the anode is

made the pole of a strong electro-magnet. This retreat, while the magnetic field remains constant, occupies several minutes and seems to indicate a decrease in the conductivity of the gas due perhaps to an increase of temperature caused primarily by an increased admittance due to the magnetic field.

II. Magnetic Field and Electric Discharges.

I wish to acknowledge my indebtedness to previous workers in the field which I enter, especially to Lehmann (Drude's Ann., No. 7, p. 1, 1902); and since Professor J. J. Thomson has given a valuable résumé of papers on this subject in his treatise entitled "Conduction of Electricity through Gases, 1903," I refrain from repeating a bibliography here.

The production of the phenomena described in this paper depends primarily on strong, steady currents, high voltage, and powerful magnetic fields. The effects were excited in cylindrical glass tubes of large diameter; these tubes were always connected to the pump. The current was regulated by a running water resistance and the amperemeter and electrometer were suitably connected.

The cathode consisted of a rod of soft iron 16 cm. in length, 2 cm. in diameter. The rod was sealed into the tube by means of a platinum wire which, in turn, was soldered to the rod of iron. This rod formed the core of an electro-magnet. A similar rod of iron with a coil of wire forming another equal electro-magnet could be placed in any position outside the tube. Thus the magnetic lines of force could be formed along the line of flow of the current in the tube or at right angles to this flow. It was realized early in the course of the investigation that the size of the tube, the character of the electrodes, shape, and material, together with the strength of the current, electromotive force, and strength of magnetic field, could modify the phenomena in a perplexing way. Each trial seemed to bring out a new phenomenon. I will select, however, those phenomena which could be definitely repeated under known conditions, and since mere descriptions without photographs of such phenomena are not particularly clear or convincing, I have made a number of photographs of certain typical phenomena.

The mathematical theory of the effect of a magnetic field on electric discharges in rarefied gases assumes, first, that if the viscosity of the gas causes the velocity of the ion to be proportional to the force arising from the electric intensity, the motion of the ion depends on the product of the electric intensity and the strength of the field. According to the

value of this product we can have motion along the line of the electric intensity, motion at right angles to the lines of magnetic force, or motion along these latter lines. In a vacuum, where the only force acting is that of the magnetic field, there is a strong tendency in the ion to follow the lines of magnetic force. This tendency was early shown by the experiments of Plucker; it is commented upon at length in Professor J. J. Thomson's work upon electric discharges in gases, and the important paper by Lehmann gives many experimental proofs of it.

One feels strongly in the presence of the phenomena that the mathematical theory is very inadequate; and the conviction has arisen in my mind that no theory based merely upon the impact and collision of particles moving with different speeds can explain the characteristic phenomena which I shall describe. A mathematical theory which shall embrace the entire range of such phenomena must draw upon the known laws of electrodynamics, those of the kinetic theory of gases, and above all those of hydrodynamics.

I shall first describe the experience with a tube of rarefied air 36 cm. long, 4 cm. in diameter. The electro-magnets were excited by a current of twenty-five amperes. The current through the discharge tube varied from 10 milliamperes to 25 milliamperes. The difference of potential between the terminals of the tube varied from 3000 volts to 6000 volts.

1. The lines of magnetic force being along the line of discharge, the cathode forming the magnetic pole, the striations are drawn into or toward the cathode; the Faraday space can be completely annihilated, new striations being formed, and the increase being proportional to the current and the field.

2. In this experiment the tube was 15 cm. long, 4 cm. wide. The cathode was the core of the electro-magnet. This core was pointed at the end. The anode was a pointed aluminum rod. The distance between the terminals was 12 cm. At a high pressure, about 1 cm., when the only light in the tube consisted of a slight glow at the terminals, the excitation of the magnetic field drew a luminous discharge from the anode up to a Faraday space, forming at the end of the discharge a very sharp line of demarcation, with one or two striae. This luminous discharge came up slowly, and retreated very slowly, after a minute or two, into the anode. The pressure was far below the ordinary stratification stage without the influence of magnetism.

3. At a lower pressure, 2 mm., a series of striae emerged from the anode with a bulge at their centre (Figure 2).

At still lower pressures ring-formed striae issued from the anode and

travelled slowly toward the cathode. These rings seemed to be formed primarily from the gases which came out of the electrode. In all cases the bulge at the centre of the striae disappeared when the water resistance was greatly increased or a spark gap was inserted in the exterior circuit. The diminution in the density of the positive carriers in the central line of discharge seemed to bring out the diverging effect of the magnetic field on the cathode ions shown by the luminous effect of the collisions in a ring form. This ring form is more strongly developed near the cathode.

Figure 3 is a photograph of two of these rings taken in perspective. The walls of the tube distort the appearance, but the ring character of the striae, I believe, is shown.

The table on page 636 shows the effect of the magnetic field with varying pressure and varying currents. The lines of magnetic force are, in every case, directed along the line of discharge.

In all cases there was an increase in the cathode light when the magnetic field was excited. If the increase or diminution of the light in the tube due to the magnetic field was plotted as an ordinate and the pressure as the abscissa of a curve, it was seen that at 1 cm. pressure the light rose to a maximum with a current of 6 milliamperes, then fell very slowly with increasing current. At 3 mm. pressure light increased with comparatively weak currents. At 1 mm. pressure light decreased, the ordinate representing the strength of light becoming negative, the curve crossing the axis of X. There seemed to be several critical points.

4. The tube in this experiment was 36 cm. long, 4 cm. wide. The rod of iron, forming one terminal, was provided at its end with an aluminum disc diameter. The coil described in Experiment 1 formed with the rod of iron the electro-magnet. When the aluminum disc formed the cathode, at pressures below the stratification point, between 2 cm. and .5 mm., the violet light on the cathode enlarged from a spot, so as to cover apparently uniformly the entire rim of the disc, while luminous streams emerged from the edges of the disc. The effect of the magnetic field was to drive the discharge away from the centre of the magnetic field.

5. When the disc was made the anode, the effect of the field was just the opposite. The discharge was drawn to the centre of the field.

6. A revolving mirror was so arranged that an image of the aluminum disc was thrown into a camera, the tube was covered with black paper so that the light only of the cathode was reflected into the camera. The photograph (Figure 4) shows a unipolar rotation. This increased in

velocity of rotation as the pressure of air in the tube was diminished. The effect of the magnetic field is to separate the discharge from the cathode into two discharges, one a violet glow, the other a plume-like orange light, which seems to extend across both cathode dark space and Faraday space. Its presence is shown by the flaring light on the spires of the helix of the photograph. The effect of the field at the anode also is to separate the discharge into a plume-like rose discharge and a smaller plume-like violet discharge. These discharges also rotate about the pole.

1 Cm. Pressure.		
Current in Milliamperes.	No. of Striae without Magnetic Field.	No. of Striae with Magnetic Field.
6	0	4 striae. Slow advance to cathode.
18	0	2 striae. Very slow retreat to anode.
20	0	No striae. Slow retreat to anode.
3 Mm. Pressure.		
9	4	5
17	3	2
20	0	0
1 Mm. Pressure.		
20	0	No striae. Instantaneous retreat of glow at the anode.
.5 Mm. Pressure.		
6	0	3
10	0	3
20	2	5
.25 Mm. Pressure.		
20	0	Continuous discharge from anode to cathode.

7. The electro-magnet was placed with its core at right angles to the line of discharge at the anode. The discharge was thrown up or down,

the direction being dependent naturally upon the direction of the current and the polarity of the field. The space around the anode was cleared of the striae, which existed before the field was excited; but the striations just beyond the most intense portion of the field were broken up into smaller striae.

8. The electro-magnet was placed at right angles to the cathode. The discharge was thrown up or down according to known electro-magnetic laws, but in addition striae were formed at a stage of pressure far below the ordinary stratification stage, at pressures of 2 cm. to .5 mm.

9. The electro-magnet was placed at right angles to the discharge at a distance from either electrode, in the centre of the tube (Figure 5). What may be called the magnetic striae appeared on the diverted path of discharge. These striae only appear with strong currents at comparatively high pressures, 2 cm. to .5 mm.

10. The ordinary form of X-ray bulb does not lend itself easily to the application of the magnetic field, either at the anode or the cathode; and even in the special form of bulb which I have used in this investigation it was not possible to develop magnetic lines of force over the entire surface of the anode or the cathode. The cores of the electro-magnets were hollow in order to allow of the approach of the coil of the electro-magnet to the terminals of the bulb, the glass seals of these terminals thus projecting into the hollow iron cores; only a circular area, therefore, on the cathode or anode forms the effective magnetic field. It seems probable that the best results would be obtained by inclosing the iron cores entirely inside the bulb, platinizing the end of the iron core forming the anode, placing the aluminum mirror forming the cathode directly in the end of an iron core and nickel plating both iron cores to prevent the constant escape of gases from such large surfaces of iron. I had a bulb constructed of this general description, but found it impossible to exhaust it to the X-ray stage on account of the escape of gases from the iron; the iron was not nickel-plated, however. The bulb was exhausted while it was strongly heated in an oven.

Figure 6 is a photograph of the discharge in the X-ray bulb somewhat before the X-ray stage; a dark space surrounds the cathode.

Figure 7 is a photograph of the same tube when the magnetic field is applied to the anode. This cone of rays is solid until just before the X-ray stage; then it becomes hollow; and at the X-ray stage it appears only at the instant the magnetic field is excited as a violet light, and then becomes indistinguishable in the fluorescence of the bulb. A violet brush, however, persists on the surface of the anode at the X-ray stage.

When the vacuum was increased to so high a degree that the bulb could not be excited by a coil giving a six-inch spark, the application of the magnetic field immediately resulted in the production of the rays.

At the X-ray stage, when the cathode formed the end of a powerful electro-magnet and the lines of magnetic force were directed along the line of discharge, a violet light in the form of a ring appeared on the back of the cathode toward the magnet, while the X-rays were greatly increased in brilliancy together with the general fluorescence of the tube.

The increase in the X-rays, however, only appeared in a tube highly exhausted and with the employment of a coil giving a twenty-four inch spark. The coil was also provided with large condensers. The increase in brilliancy of the X-rays viewed on a fluorescent screen was fully one hundred per cent, and this increase suggests the possibility of a practical use of the magnetic field in connection with the production of X-rays. One can modify the state of the tube by modifying the magnetic field. It may be also that by studying the effect of the field we can identify the particles which bombard the anticathode.

It was difficult to measure the strength of the magnetic field inside the exhausted bulbs. The size of the electro-magnet was as follows: Diameter of core, 2.5 cm.; 15 layers of no. 12 copper wire, 37 turns to a layer; length of electro-magnet, 9.5 cm.; distance of end of hollow iron core from anode or cathode, 2 cm. Exciting current in electro-magnet, 15 to 25 amperes.

When the cathode mirror of an ordinary X-ray bulb is made the anode instead of the cathode, the current passing in the usually unfavorable way for the production of the rays, and at the same time is also the pole of a powerful electro-magnet, the bulb gives out X-rays in great abundance. This is not the case when the magnet is not excited. The magnetic field, therefore, causes the anode to produce X-rays, probably by an increased energy of bombardment of the platinum focal plane by the positive ions. I believe that if one studies the effect of the magnetic field on the anode, in the case of the stratifications showing an effect of increased pressure at their centres (Figure 2), the production of ring stratifications, one must be convinced that the effect of the magnetic field is to increase the free path of the positive ion and to permit it to produce the X-rays by a bombardment similar to that of the negative ion. There is another supposition, namely, that the magnetic field produces rays similar to the cathode rays; certainly one can separate the anode discharge into two by means of the magnetic field.

Figure 8 is a photograph of the X-ray bulb when the cathode mirror has been made the magnetic pole. Without the excitement of the magnetic field the bulb could not be made to give the X-rays even with a coil producing a six-inch spark, the vacuum having increased greatly during the previous use of the bulb. When the field was excited, however, a brilliant fluorescence was produced without any appearance of X-rays. The negative ions apparently did not reach the anticathode, but instead formed fluorescent rings around the cathode. The cathode is thus made part of a hollow hemisphere of, in this case, orange light. When, however, the bulb was excited by a coil giving a twenty-inch spark with Leyden jars, the bulb gave very brilliant X-rays at the moment of exciting the magnetic field. In the case of the use of the six inch spark coil there were no Leyden jars in the circuit.

Besides the scientific side of the manifestations of the effect of the magnetic field on discharges in high vacua, there seems to be a practical use of the electro-magnetic field in connection with the regulation of the discharge in X-ray bulbs. At present, when the vacuum has risen so high that the bulb cannot be excited, one is forced to apply heat to various regulators in order to drive out gases to increase the conduction. All regulators hitherto used are uncertain and dangerous to the life of the bulb in their application. I believe that a magnetic regulator applied to the anode would be of great service in hospital plants where a suitable electrical equipment can be had. The magnetic regulator is entirely safe and is constant in its action. It also enables one to pass readily from the production of hard rays to that of soft rays by the modification of the strength of the magnetic field, a modification difficult to accomplish without the application of the magnetic field.

In Experiment 1 can we not say that the revolving factor in the case of the negative ion is greater than its progression factor? The energy, therefore, along the line of discharge is less to oppose the energy of the positive ion, and the negative ion is therefore diverted from the line of discharge, thus allowing the positive column to advance to the cathode.

In Experiment 5 the revolving factor is less than the progression factor, the discharge is ejected from the centre of the magnetic field. This is independent of the name of the magnetic pole.

In Experiment 6 the revolution of the cathode light indicates this superior revolution factor in the case of the negative particle. This is independent of the name of the magnetic pole.

In Experiment 10 we see the positive particles driving back the negative particles so as to diminish the dark cathode space.

In Experiment 3 the formation of the rings indicates a superior pressure of the positive particles shot out from the positive pointed terminal against a diminished pressure of the discharge from the plate terminal of the cathode. This manner of formation is analogous to that of smoke rings.

In Experiment 8 the revolving factor is greater than the progression factor for both the positive and the negative ions, and the effect of the field is to retard the discharge. The field seems to oppose an obstacle like that of a rock in a running stream producing ripples.

The theory of positive and negative ions moving with different velocities and colliding according to Townshend's Hypothesis, — an hypothesis which is illuminating in regard to electric discharges in general, — does not throw much light upon the phenomenon of striae. It does not seem possible to form striae by the indiscriminate projection of colliding particles. Such striae, or stratifications, are analogous to standing waves in a liquid, and if we suppose electric pulsations issuing both from the cathode and the anode we can perhaps conceive of the method of formation of the stratifications. Even with the employment of the steady current from a storage battery a high note is heard in a telephone intercalated in the circuit which is not due to crepitations in the liquid resistance employed.

The unipolar rotation described in Experiment 6 leads my mind to connect the phenomenon of coronal streamers seen at the poles of the sun in an eclipse with the effect of a magnetic field on possible electrical discharges between the equatorial regions of the sun and the poles of the sun. If we suppose that a difference of electrical potential can arise between the swiftly moving strata of gases or from the eruptions which take place mainly along the equatorial belt and the polar regions, the magnetic poles of the sun would undoubtedly tend to cause the resulting electric discharges to revolve about the pole. On account of the vast circumferential area about the poles a number of discharges could occur at different points around the pole and each discharge would revolve under the effect of the pole. In observing the effect of a strong magnetic pole on plate terminals in wide tubes of rarefied air at comparatively high pressure of air under conditions of high electromotive force and great current density, one can observe phenomena of rotation which cannot be photographed, yet which present to the eye a strong analogy to the appearance of coronal streamers.

I have arranged a number of collections of bristles on a disc, which was then set in rapid rotation. Figure 9 is a photograph of the appear-

ance of such revolving streamers which fairly represent what may be seen at the terminal of a discharge tube in a magnetic field, and call to mind the coronal streamers. The magnetic phenomenon described in 8 may also have a bearing upon the coronal streamers at the poles of the sun. When the lines of magnetic force are at right angles or transverse to the direction of the electric discharge, at comparatively high pressures, one to two centimeters with currents from 5 to 20 centimeters, 3,000 to 8,000 volts in wide tubes, streamers radiate from the position of the magnetic pole. It will be noted that these striae make their appearance at a much higher pressure than that of the usual striae in rarefied gases.

Thus electric discharges around or toward the poles of the sun transverse to the lines of magnetic poles of the sun could be separated into streamers. What conclusions can we draw from such varied phenomena? A short consideration of the elementary mathematical treatment given by J. J. Thomson in his treatise on "Discharge of Electricity through Gases" will help us, I think, to analyze the phenomena. Professor Thomson discusses the case of one ion moving through a gas, the viscosity of the gas causing the velocity of the ion to be proportional to the force acting upon it. Since there is a mechanical force acting upon the ion perpendicular both to the electric force and the direction of the magnetic force, we have

$$\left.\begin{matrix} X \\ Y \\ Z \end{matrix}\right\} \begin{matrix}\text{components of} \\ \text{electric force,}\end{matrix} \quad \left.\begin{matrix} \alpha \\ \beta \\ \gamma \end{matrix}\right\} \begin{matrix}\text{components of} \\ \text{magnetic force,}\end{matrix} \quad \left.\begin{matrix} u \\ v \\ w \end{matrix}\right\} \begin{matrix}\text{components of} \\ \text{magnetic force.}\end{matrix}$$

Components of mechanical force X_ϵ, Y_ϵ, Z_ϵ, ϵ being the charge on the ion, R the velocity of the ion under unit electric intensity. We then have

$$\epsilon\,(\beta w - \gamma v),$$
$$\epsilon\,(\gamma u - \alpha w),$$
$$\epsilon\,(\alpha v - \beta u).$$

$$u = R\,(X + \beta w - \gamma v),$$
$$v = R\,(Y + \gamma u - \alpha w),$$
$$w = R\,(Z + \alpha v - \beta u).$$

$$u = \frac{R X + R^2 (\gamma Y - \beta Z) + R^3 \alpha\,(\alpha X + \beta Y + \gamma Z)}{1 + R^2 (\alpha^2 + \beta^2 + \gamma^2)},$$

$$v = \frac{R Y + R^2 (\alpha Z - \gamma X) + R^3 \beta\,(\alpha X + \beta Y + \gamma Z)}{1 + R^2 (\alpha^2 + \beta^2 + \gamma^2)},$$

$$w = \frac{R Z + R^2 (\beta X + \alpha Y) + R^3 \gamma\,(\alpha X + \beta Y + \gamma Z)}{1 + R^2 (\alpha^2 + \beta^2 + \gamma^2)}.$$

Since it is supposed that there is not only a negative particle ϵ shot out from the negative terminal, but also a positive particle ϵ' shot out from the positive terminal, we have similar expressions for u_1, v_1, w_1, for the velocity of the positive particle.

Professor Thomson analyzes thus the equations for u, v, w. The first term in the numerator represents a velocity parallel and proportional to the electric force; the second term, a velocity at right angles both to the electric and magnetic forces. The third term represents a velocity parallel to the magnetic force. The relative importance of these terms depends upon the value of $R\ H$. If this quantity is small the first term is the most important, and the ion moves parallel to the electric force; if, on the other hand, $R\ H$ is large, the last term is the most important and the ion moves parallel to the magnetic force. As R varies inversely as the pressure of the gas, it might, at very low pressures, be possible to make $R\,H$ large enough and thus make the ions travel along the lines of magnetic force. The same reasoning can doubtless be applied to the movement of the positive particle, and we then have a consideration of the relative rotation effect under the influence of the magnetic field on the two particles, the negative and the positive, and the relative progression effect along the lines of magnetic force. In the discussion also we must bear in mind the fruitful hypothesis of Townshend in regard to the collision of the ions.

It may be that the difference in magnetic properties of oxygen and hydrogen contained in the rarefied air also plays an important part in the phenomena which are presented in this paper. I hope to present later the results of a study of the behavior of oxygen and other gases submitted to electric discharges in a magnetic field. The conclusions I draw from these experiments are as follows:—

1. Strong, steady currents and high differences of potential introduce us to phenomena which are concealed by inadequate currents, low potential differences, and weak magnetic fields.

2. At definite pressures, where the free path of the molecule is short, the cathode violet light is repelled to the edge of the circular disc forming the cathode by a magnetic field, the lines of which are directed along the line of electric discharge, and revolves with a speed dependent upon the pressure of rarefied air. We have, in this case, a distinct unipolar rotation. Besides the violet light, there is also a rotation of an orange-colored plume-like discharge.

3. When the anode is made the core of an electro-magnet at high pressures, the discharge is separated into two; one a violet discharge,

the other a rosy red discharge. These discharges are brought to the centre of the disc constituting the end of the anode, instead of being repelled to the edge of the disc, as in the case of the cathode (see 2 above). The effect in both 2 and 3 is independent of the name of the pole.

4. When the cathode light suddenly diminishes, at a definite pressure caused by the sudden introduction of air, ring-shaped striae issue from the anode and travel toward the cathode.

If a spark gap is introduced in the exterior current circuit, the cathode light diminishes and ring-shaped striae issue from the anode. The energy of projection of the negative particle apparently diminishing quicker than the larger positive particle, the stream of the latter issuing at a greater density from a pointed electrode, can form a luminous ring analogous to vortex rings.

5. The suppositions that under certain conditions of free path the negative ion is diverted more readily from the line of discharge under the influence of the magnetic field than the positive ion; or, in other words, has a greater energy of movement around the lines of magnetic force than of energy along the line of discharge, and that the reverse holds for the positive ion seemed to be borne out by experiment.

6. The formations of what I have termed magnetic striae, when the magnetic field is at right angles to the line of discharge, seems to indicate that the revolving factor of both negative and positive ions being greater than their energy along the path of discharge, the discharge is hampered, as if in a flow of a liquid an obstacle should be interposed, thus forming ripples.

7. If we suppose pulsations issuing at different rates from the two terminals of the discharge tube we can by hydrodynamical analogies get an insight into the formation of stratifications.

8. When the cathode forms the end of a powerful electro-magnet under suitable conditions the output of X-rays is greatly increased.

9. A new form of discharge is seen in case 8 on the back of the cathode. If these are canal rays, they are formed without a canal.

10. The fluorescent light on the walls of the X-ray bulb revolve through a comparatively large angle about the pole.

11. When the anode in an X-ray bulb is also the end of a powerful electro-magnet the application of the magnetic field results in the production of X-rays from a bulb which cannot be excited without the application of heat.

12. When the anode forms the magnetic pole a violet brush-like light

appears on the anode, on the side away from the electro-magnet, while the fluorescent light is forced somewhat beyond the cathode.

13. The use of Leyden jars in the case of low potential coils greatly modifies the effect of the application of the magnetic field, while with coils giving sparks of over 20 cm. with comparatively large Leyden jars in circuit, the application of the magnetic field to either anode or cathode results in greatly increased production of X-rays.

14. The application of a strong magnetic field at the anode, with lines of force along the line of electric discharge, forms a safe and useful method of regulation of X-ray bulbs.

15. The application of the magnetic field at a suitably placed anode constitutes a magnetic rectifier for alternating currents.

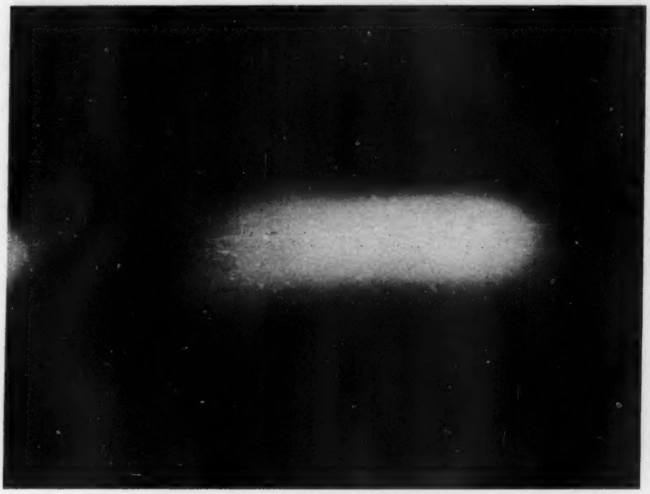

FIG. 1.

FIG. 2.

FIG. 3.

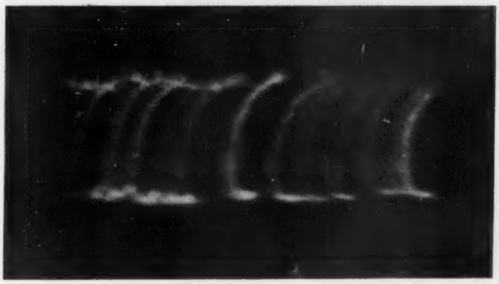

FIG. 4

FIG. 5.

FIG. 6.

FIG. 7.

FIG. 8.

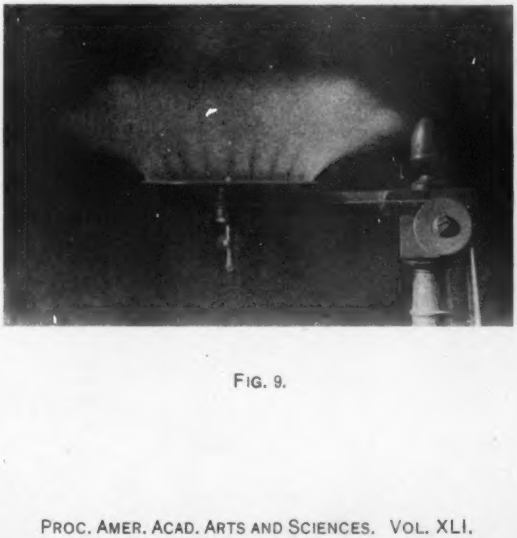

FIG. 9.